Effects of Noise and Tonal Stimuli on Hearing in Pinnipeds

Dr. David Kastak
Institute of Marine Sciences
Long Marine Laboratory
University of California, Santa Cruz
100 Shaffer Rd.
Santa Cruz, CA 95060
phone: (831) 459-3345 fax: (831) 459-3383 email: kastak@ucsc.edu

Dr. Colleen Reichmuth
Institute of Marine Sciences
Long Marine Laboratory
University of California, Santa Cruz
100 Shaffer Rd.
Santa Cruz, CA 95060
phone: (831) 459-3345 fax: (831) 459-3383 email: coll@ucsc.edu

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LONG-TERM GOALS

The long-term goals of this effort are to assess the effects of tonal (sonar-like) and broadband noise on underwater and in-air hearing sensitivity of individuals of three species of pinniped: the California sea lion, harbor seal, and northern elephant seal. Specifically, the goals are to assess onset, growth, and recovery of noise-induced temporary threshold shift of hearing (TTS).

OBJECTIVES

The scientific objectives are to use behavioral psychophysics to determine auditory sensitivity in three pinniped subjects before, immediately after, and at least 24 h following exposure to a fatiguing stimulus of a given duration and sound pressure level. Hearing loss induced by tonal stimuli will be compared to that induced by broadband noise, and comparisons between hearing loss in air and in water will be made in order to determine whether species differences (e.g., based on auditory anatomy) play a role in differential responses to airborne and waterborne sound, and whether losses incurred in water translate to equivalent losses in air.

APPROACH

The approach is a test/re-test paradigm in which auditory thresholds are obtained under three conditions relative to exposure to an intense sound: pre-exposure, post-exposure (immediately following exposure), and recovery (a minimum of 24 h post-exposure). Testing primarily occurs in water where the fatiguing stimulus is a pure tone of 4.1 kHz and variable in duration and level. All testing and exposure sequences are performed voluntarily by the subjects using operant conditioning and fish reinforcement.

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Water

All underwater testing takes place in a 7.51-m diameter pool with a depth of 2.5 m. The subjects are trained to station using a chin cup one meter from a sound projecting hydrophone mounted near the wall of the pool at a depth of 1 m. Auditory thresholds are determined using a descending staircase procedure where the signal level is decreased following a correct detection and increased following a miss. Signal detections are reported via a paddle press by the subject. Trial periods are delineated by a small light that is turned on at the beginning of a trial and turned off at the end of a four-second interval. There are four to six trial intervals per dive, following which reinforcement and re-stationing occur. Verbal feedback is provided in the event of a correct detection or correct rejection. Incorrect responses are followed by a variable waiting period before the next trial begins. Thresholds are determined by averaging the signal levels corresponding to the upper and lower reversal points of a nine-reversal track. Test frequencies are 4.1 kHz (exposure frequency), 5.8 kHz (one-half octave), and 8.2 kHz (one octave).

Fatiguing stimulus (FS) exposure takes place immediately following pre-exposure threshold determination. The FS is a pure tone at a frequency of 4.1 kHz with durations of 30 s or 60 s and levels ranging from 161 to 184 dB re 1 μPa. In addition to absolute levels, the exposure stimuli are referenced to a baseline threshold determined during the course of training for each subject.

Following exposure, the subject re-positions at the threshold testing station for post-exposure testing. This process is repeated at least 24 h after the exposure. If the threshold is within +/- 3 dB of the established baseline threshold, a new exposure sequence proceeds on the following day. If the threshold is elevated, subsequent exposures are delayed until the threshold returns to the baseline level. Threshold shifts are defined by subtracting post-exposure thresholds from pre-exposure thresholds, with positive values indicating a threshold shift and zero and negative values indicating lack of a shift.

Air

Testing in air is conducted in essentially the same way as that under water; however, in-air testing takes place in a hemi-anechoic chamber that is divided into a 3 x 5.6 m testing section and adjacent control room. During testing the subject occupies the testing section while the trainer and experimenter occupy the control room. An apparatus analogous to the one used underwater, comprising a chin cup and response paddle, is used for in-air testing. The chin-cup faces an in-air projector that delivers the audiometric test stimuli; the fatiguing stimuli are projected by a separate transducer located to the subject's right. Similarly to the underwater procedure, a light delineates individual trials; however, in air, reinforcement is delivered on a trial-to-trial basis, rather than after blocks of trials.

WORK COMPLETED

Equipment for the under water experiment has been acquired and calibration of the audiometric testing and noise-emitting transducers has been completed. Spatial variability of the FS (4.1 kHz pure tone) and test tones (frequency-modulated signals, 10% modulation, 4.1 kHz, 5.8 kHz, 8.2 kHz) in the test tank has been estimated and spacing of transducers, hydrophones, and subject positioning in order to optimize testing have been determined. Baseline thresholds at 4.1 kHz and 5.8 kHz have been obtained for the harbor seal. Test/exposure sequences at FS levels ranging from 161 to 184 dB re 1

μPa and durations of 30 and 60 s have been completed. Threshold shifts have been assessed at the exposure frequency (4.1 kHz), one-half octave above the exposure frequency (5.8 kHz – in water and in air), and one octave above the exposure frequency (8.2 kHz). Recovery is currently being tracked for this subject after the highest exposure (184 dB re 1 μPa/60 s). A second subject (northern elephant seal) is completing baseline threshold determination under water in preparation for test/exposure sequences.

RESULTS

The primary results relating to TTS involve one subject (harbor seal). This animal showed threshold shifts ranging from zero to nine dB at a test frequency of 5.8 kHz after being exposed to 4.1 kHz pure tones ranging in sound pressure level from 161 to 180 dB re 1 μPa at durations of 30 s. This subject showed a moderate threshold shift that recovered within 10 min after a single exposure of 184 dB re 1 μPa for 60 s. A second exposure using the same parameters induced a threshold shift of over 50 dB at 5.8 kHz and over 20 dB (estimated) at the exposure frequency of 4.1 kHz. Recovery from this exposure is ongoing and has reached a length of 10 days. The threshold shift has fully recovered at the exposure frequency but remains between 10 and 15 dB at the half-octave frequency. Testing in air shows a similar degree of shift at the 5.8 kHz test frequency.

When corrected for recovery occurring within a test session, threshold shift was shown to be an increasing function of sound exposure level, with significant shifts occurring at a sound exposure level of 198 dB re 1 μPa2s. The sound exposure level corresponding to the highest shift was approximately 202 dB re 1 μPa2s. The rate of recovery from threshold shift at one-half octave above exposure frequency is approximately 9.4 dB/log(min), similar to the value of 8.8 obtained from another pinniped subject exposed and tested in air (Kastak et al., in press).

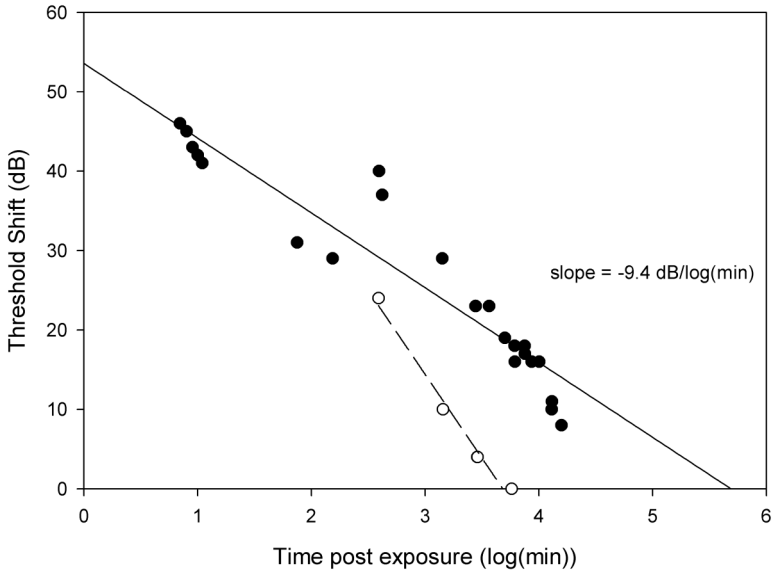

Figure 1. Recovery of threshold shift in a harbor seal exposed to a 4.1 kHz pure tone of 184 dB re 1 μPa for a duration of 60 s. Slope of the recovery function is -9.4 dB/log(min) for threshold shifts at 5.8 kHz (solid symbols, solid line). The recovery slope for the 4.1 kHz test frequency (hollow symbols, dashed line) appears to be steeper; however, the first post-exposure thresholds obtained at 4.1 kHz were not obtained until 6.5 h after exposure.

IMPACT/APPLICATIONS

These results will affect regulatory issues regarding exposure of marine mammals to noise, and influence noise mitigation efforts by users (including military) of tonal stimuli projected in water.

RELATED PROJECTS

None

PUBLICATIONS

Kastak, D., Reichmuth, C., Holt, M.M., Mulsow, J., Southall, B.L., Schusterman, R.J. 2007. Onset, growth, and recovery of in-air temporary threshold shift in a California sea lion (Zalophus californianus). Journal of the Acoustical Society of America [in press, refereed].

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